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PRELIMINARY WIND IMPACT STUDY
OF
MID-TOWN CULTURAL DISTRICT
FULL BUILD PROPOSAL

BOSTON, MASSACHUSETTS

11 January 1989

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1. INTRODUCTION & SUMMARY

This report presents the results of an analysis of the wind environment around the proposed development of the so-called Midtown Cultural District in Boston, Massachusetts. The study consisted of:

- Inspection of the existing sites, site plans, and elevations of buildings and surroundings to enable qualitative analysis of wind flow patterns around the building, and to guide selection of sensor locations.
- Meeting with BRA personnel to discuss sensor locations and BRA requirements.
- Wind tunnel tests of no build and full build configurations.
- Limited on-site measurements during a sustained northwest wind event.

Key results from this study are as follows:

(1) **General Wind Conditions at Site:**

Figure 1 shows a site plan of the project area. Figures 2 and 3 are photographs taken of the wind tunnel model for the existing and proposed conditions, respectively. The project site is exposed to an open expanse (Boston Common) over roughly one half of the "compass points." Therefore, the micro-climate normally associated with such an exposed site should be a baseline set of conditions against which deviations caused by the project should be evaluated. Indeed, previous quantitative studies and on-site surveys have showed that existing wind conditions are quite severe in the area from West Street to Avery Street along both sides of Tremont and Mason Streets, and at the Tremont and Boylston intersection. The study also showed, as expected, that the primary cause of the existing high winds is frequently occurring winds from the Westerly

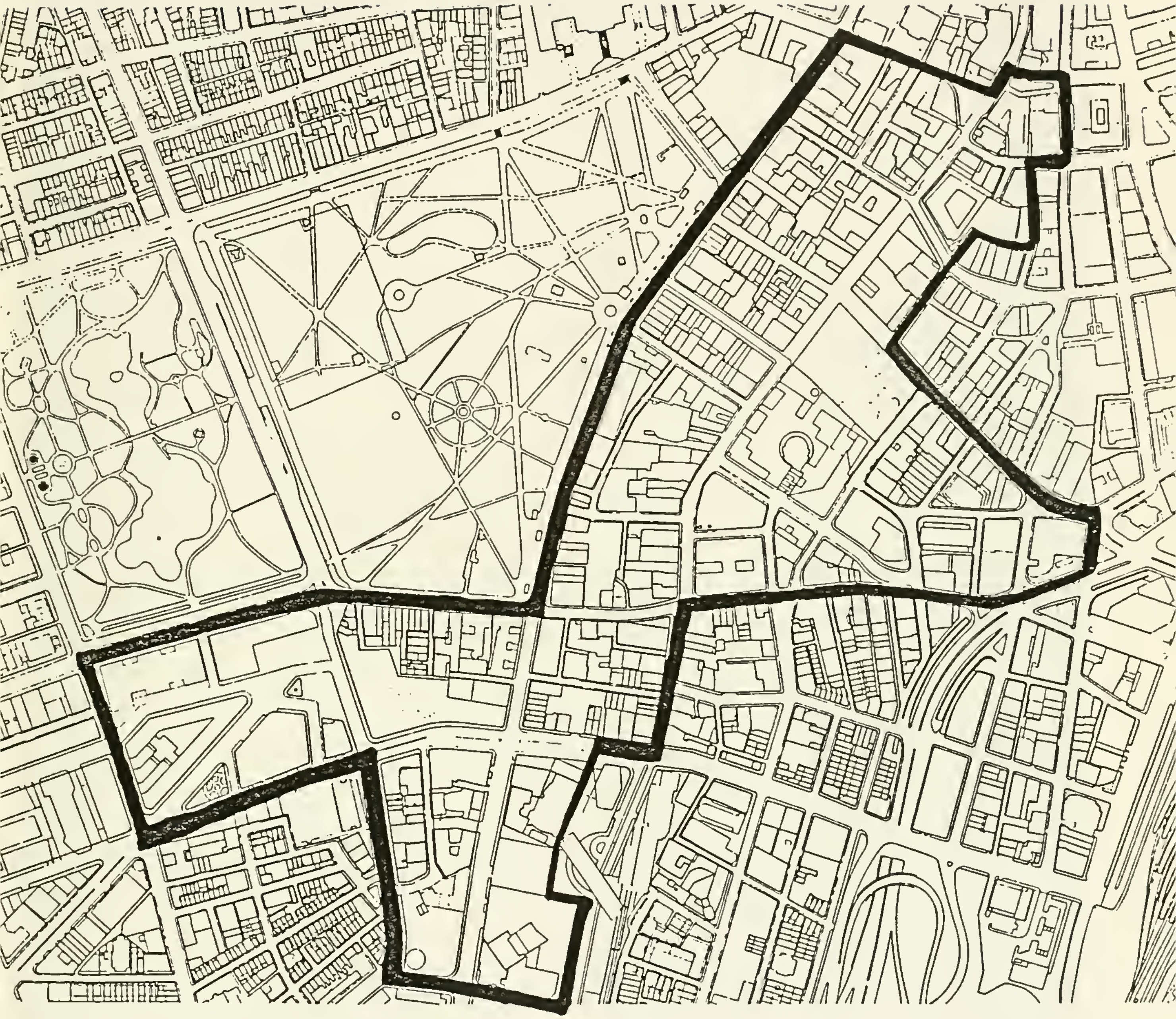


Figure 1. Location plan.

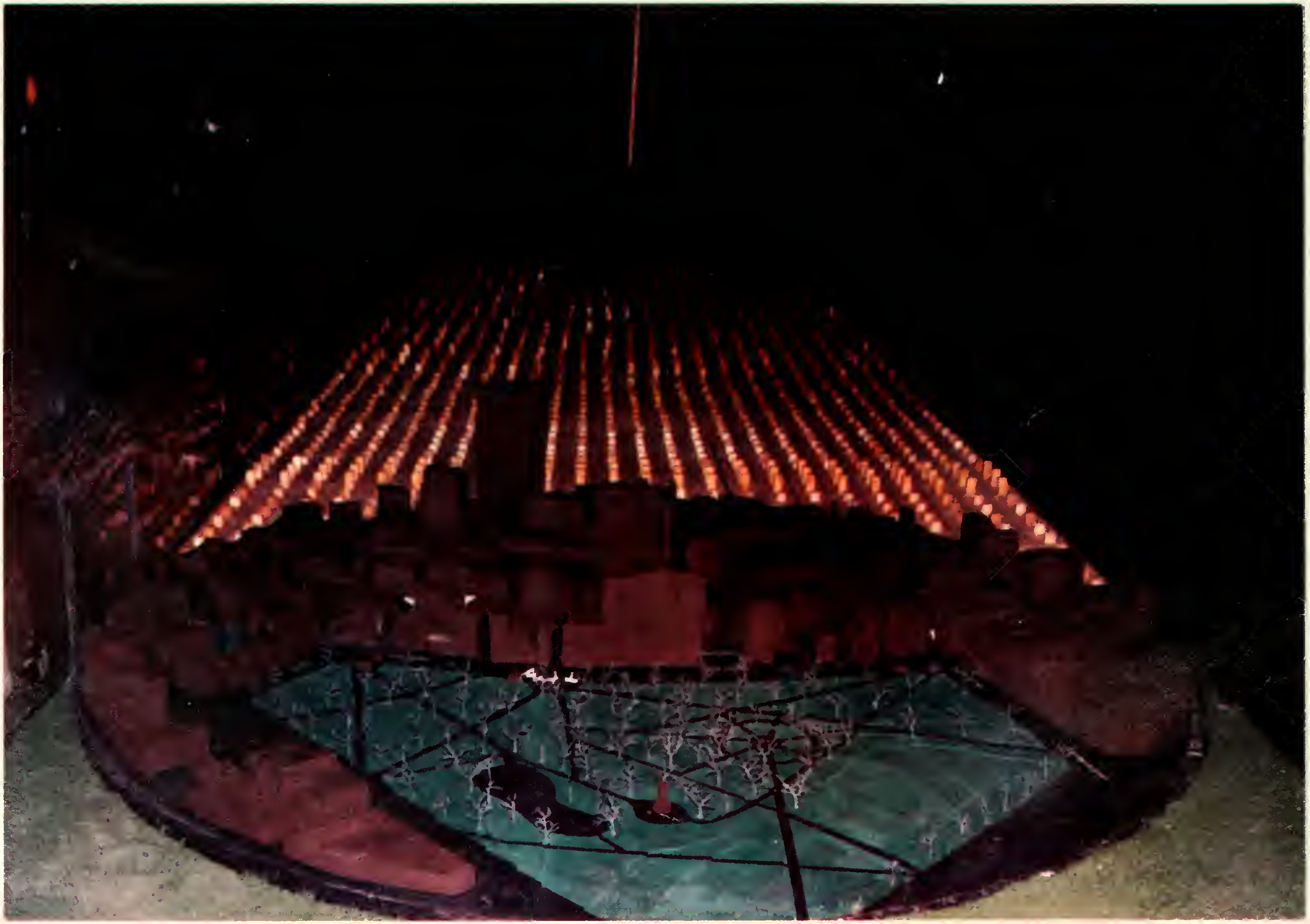


Figure 2. Photograph of wind tunnel model used for existing conditions.

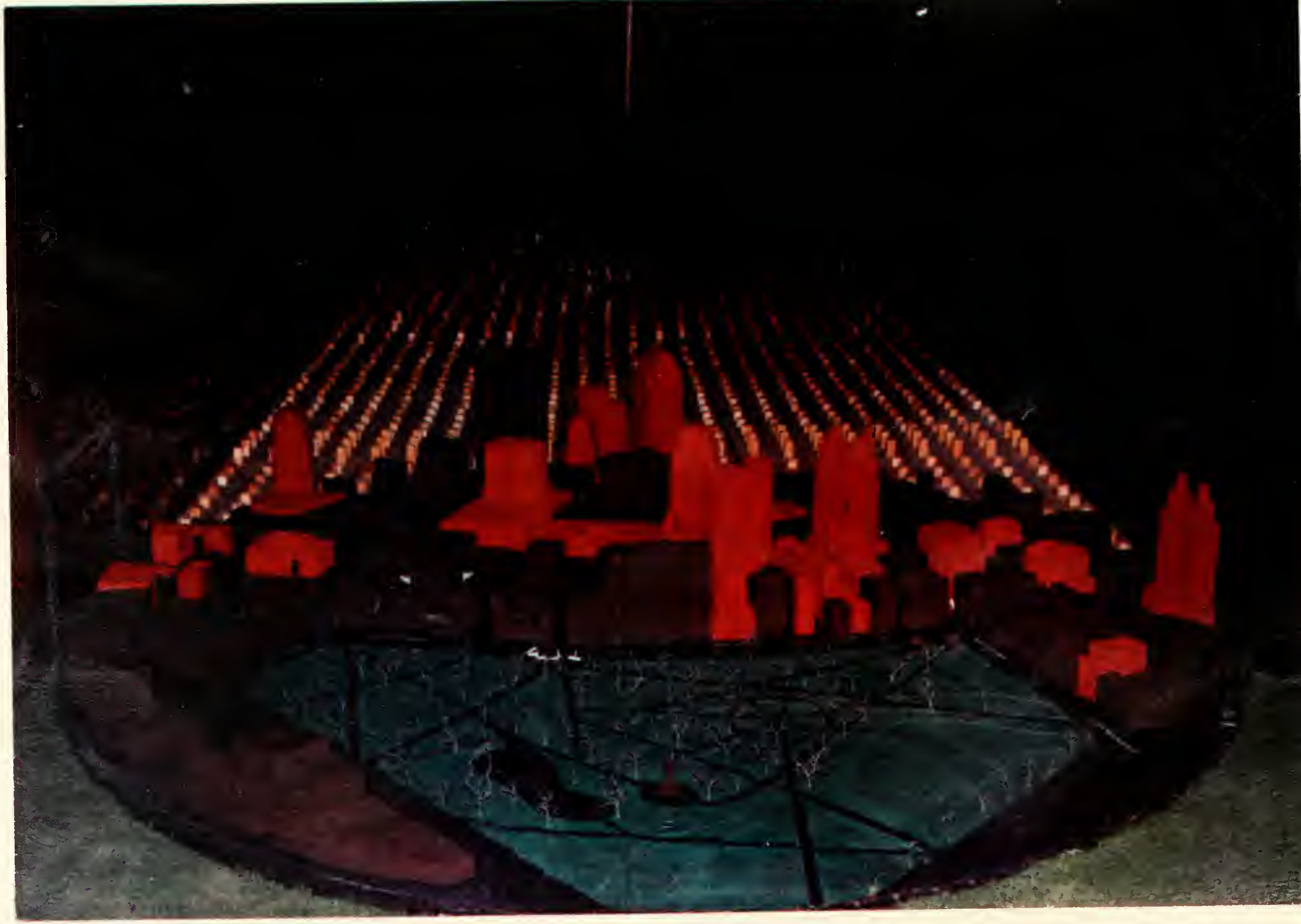


Figure 3. Photograph of wind tunnel model used for proposed conditions.

sector (NW-W-SW) blowing unimpeded across the Common and interacting with the abrupt change in surface topography created by the existing Tremont-on-the-Common (TOC) structure, and other building mass along Tremont Street.

The blocking effects created by TOC and the adjacent building mass during Westerly and Northwesterly winds (very common directions in Boston) result in winds approaching the site which are comprised of a large velocity component running along Tremont Street, accompanied by high vorticity (swirl), and a "direct" wind component attacking the site from the Boston Common. These combine to produce an energetic vortex which bends around both ends of the TOC building, and flows down Tremont toward Boylston and Temple Place seeking relief "slots" in the form of cross streets. The wind which has not been "relieved" by cross streets eventually flows around the corner at Boylston and Tremont Streets.

Winds blowing from the easterly sector (NNE-NE-E-SE-SSE) are generally interrupted by the existing high rise or mid-rise construction, and therefore are expected to be less of a factor in this project area.

(2) **Impacts of the Proposed Full Build:**

The buildings included in the full-build (proposed) condition are darkened and lettered on the site plan in Figure 4, and the key to these proposed buildings is shown in Table 1.

Favorable and adverse impacts are graphically summarized in Figures 5 and 6. The sensor locations and corresponding measurements are addressed in Sections 4 and 5.

High winds still will exist along Tremont Street, due to Tremont-on-the-Common (TOC) and other building mass which intercepts the winds blowing across the Common. Favorable impacts were found near the southern face of TOC, as the existing high speed corner flow was abated with the presence of the proposed Parkside East. Wind speeds diminish along Mason Street for westerly sector winds, due to increased sheltering of the Parkside buildings. Additional blockage of relief "slots" produced in slight wind speed increases from Avery Street to Boylston Street. At the corner of Tremont and Boylston, the effective gust velocity increased to a level above the BRA guideline of 31 mph.

Along Washington Street, amidst the Lafayette II (Campeau) and Commonwealth Center projects, windspeeds increase significantly, but remain within comfortable levels for most pedestrian activities. Downwind of these tall buildings,

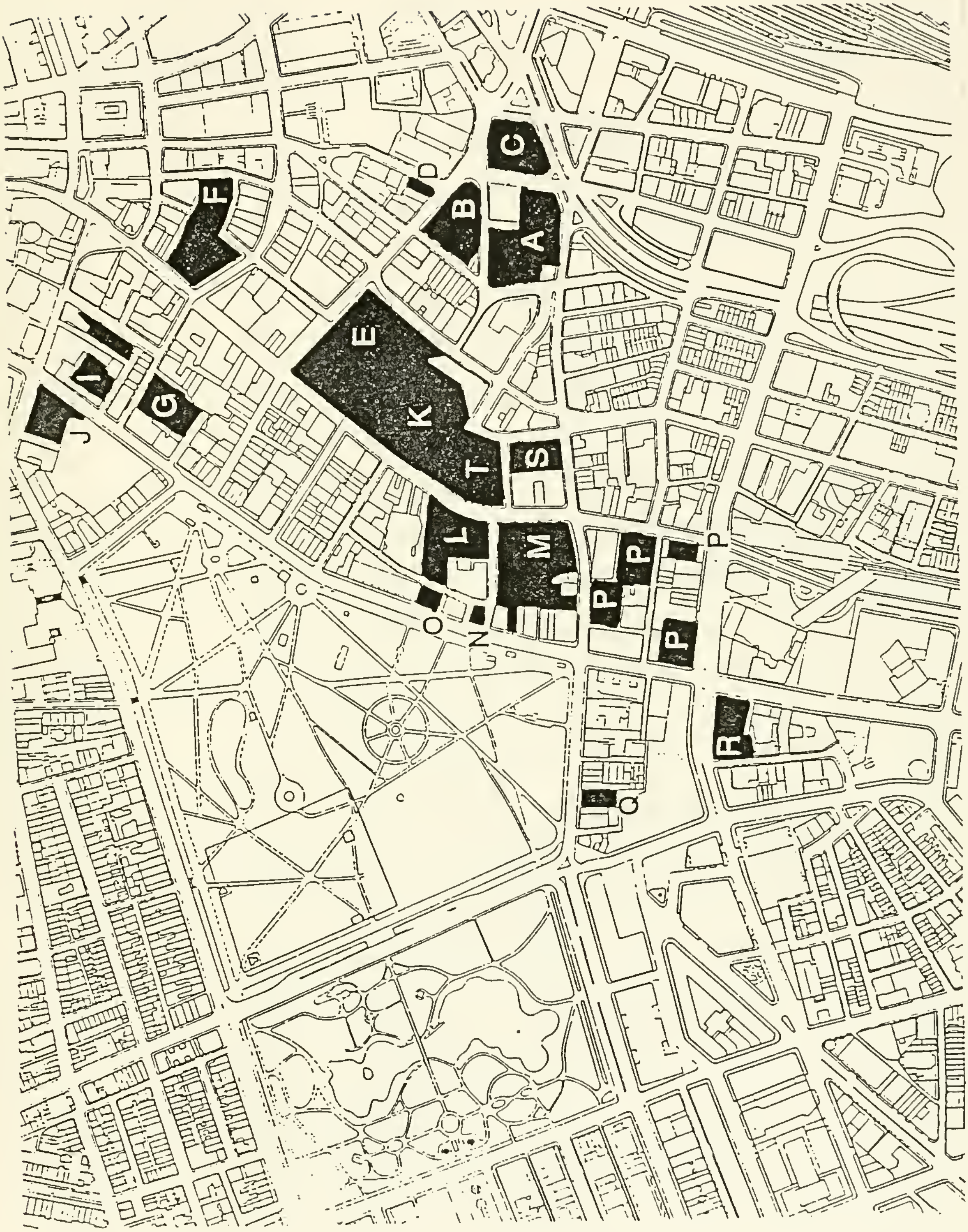
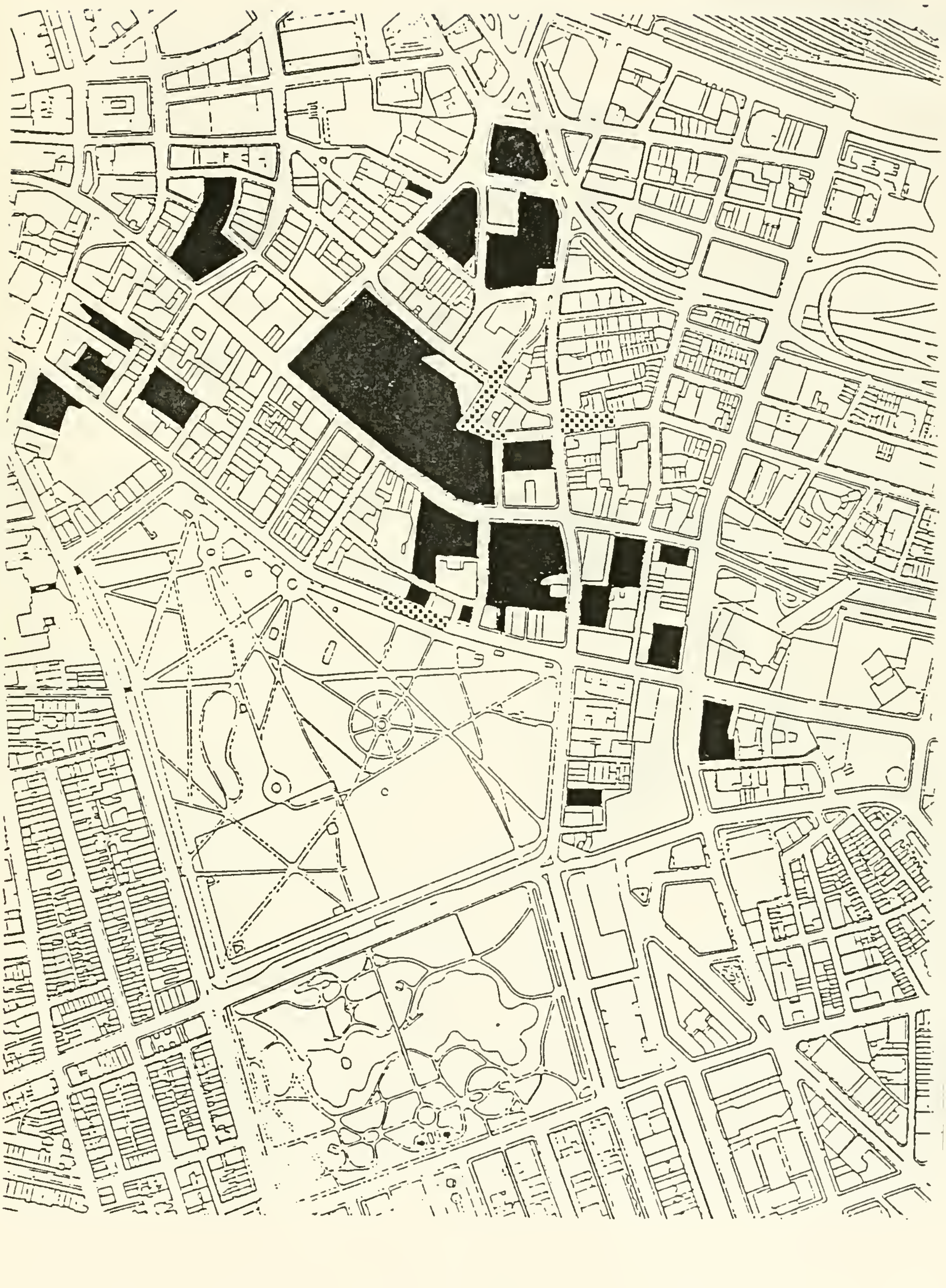

KEYS TO BUILDINGS

Figure 4. Site plan with keys to proposed buildings.

TABLE 1

Full Build
Proposed Buildings

A. Kingston-Bedford
B. 99 Summer Street
C. 125 Summer Street
D. 84 Summer Street
E. Jordan Marsh (added structure)
F. Woolworth's (added structure)
G. 110-120 Tremont Street
H. 45 Providence Street
I. 90 Tremont Street
J. 73 Tremont Street
K. Lafayette II
L. Commonwealth Center (North)
M. Commonwealth Center (South)
N. Parkside-at-Mason
O. Parkside East
P. Hinge Block (4 buildings)
Q. 146 Boylston Street
R. Parcel C-4
S. 600 Washington Street
T. Bloomingdale's



AREAS OF FAVORABLE WIND IMPACTS

Figure 5. Areas of favorable wind impacts.

AREAS OF ADVERSE WIND IMPACTS

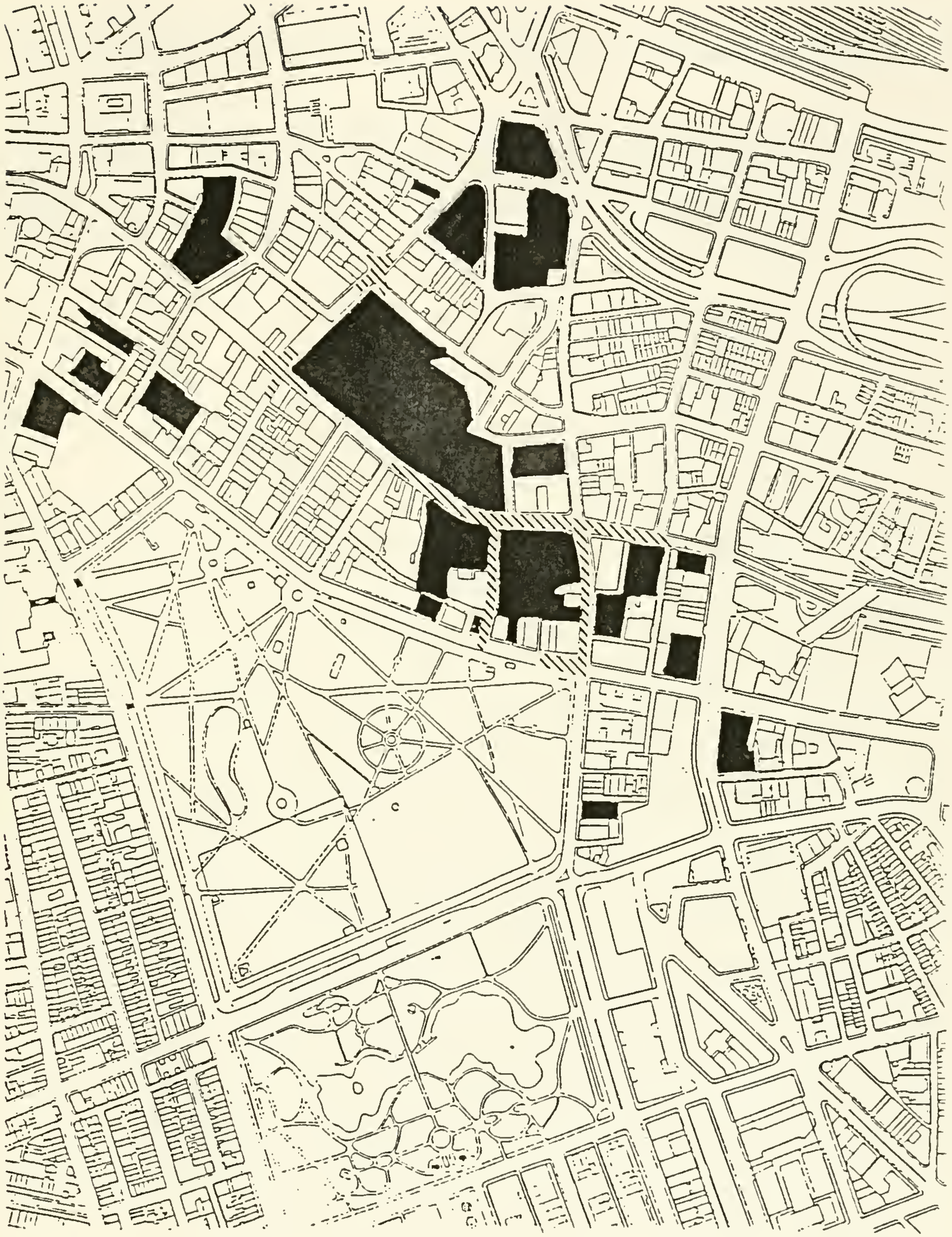


Figure 6. Areas of adverse wind impacts.

sheltering effects can occur, resulting in lower wind speeds, such as sheltering Chinatown in the face of northwesterly winds.

The Boston Common wind climate remains, on the whole, unchanged, except for those areas directly across from TOC along Tremont Street. Slight increases are anticipated in this area, but no substantial changes that affect pedestrian activities are foreseen.

2.0 OVERVIEW OF WIND EFFECTS IN URBAN SETTINGS

2.1 General

The winds blowing over the earth's surface are slowed and mixed by interaction with trees, buildings, and other features which contribute to "surface roughness." The result of this interaction is that the average wind speeds increase with elevation above the local terrain up to a level called the gradient height (usually 275 to 400 m; i.e., 900 to 1,350 ft.). Above this level, the wind speed is relatively constant and unaffected by the surface development. This region below the gradient height where the surface roughness affects the wind characteristics is known as the atmospheric boundary layer.

The interaction of the atmospheric boundary layer with building structures creates complex flow fields, which result in large variations in ground level wind speed and direction near an isolated building and/or groups of buildings.

Figure 7 shows the flow around an isolated block building which is not very tall in comparison to the gradient height. In such cases, the flow field can be summarized as follows:

- Upwind of the building, there is a zone where the approaching flow is first influenced by the presence of the building. Within this zone, both wind speed and direction are affected as the flow "attempts" to travel around and over the building. The exposed front surfaces of the building will experience a pressure higher than ambient as the approaching air decelerates. Since the vertical distribution of wind speeds diminish with decreasing height, a downward-directed pressure gradient will be established as the flow decelerates near the upwind face. This causes a downward flow along with windward surface; at the ground, this flow moves out away from the building, causing the approach flow to separate from the ground at some distance upwind. The result is "standing" eddy (vortex) in front of the lower portion of the building. The exact upwind separation location depends on the building width-to-height ratio, the upstream surface roughness, and the approach flow characteristics. Above this eddy, the incident flow strikes the building face, moving upward and/or laterally depending on its proximity to the roof or side edges. On block-like structures, the resulting boundary layer (i.e., thin "layer" of flow adjacent to the building surface) separates from the exposed surface at sharp edges where the flow cannot follow the abrupt change in direction.

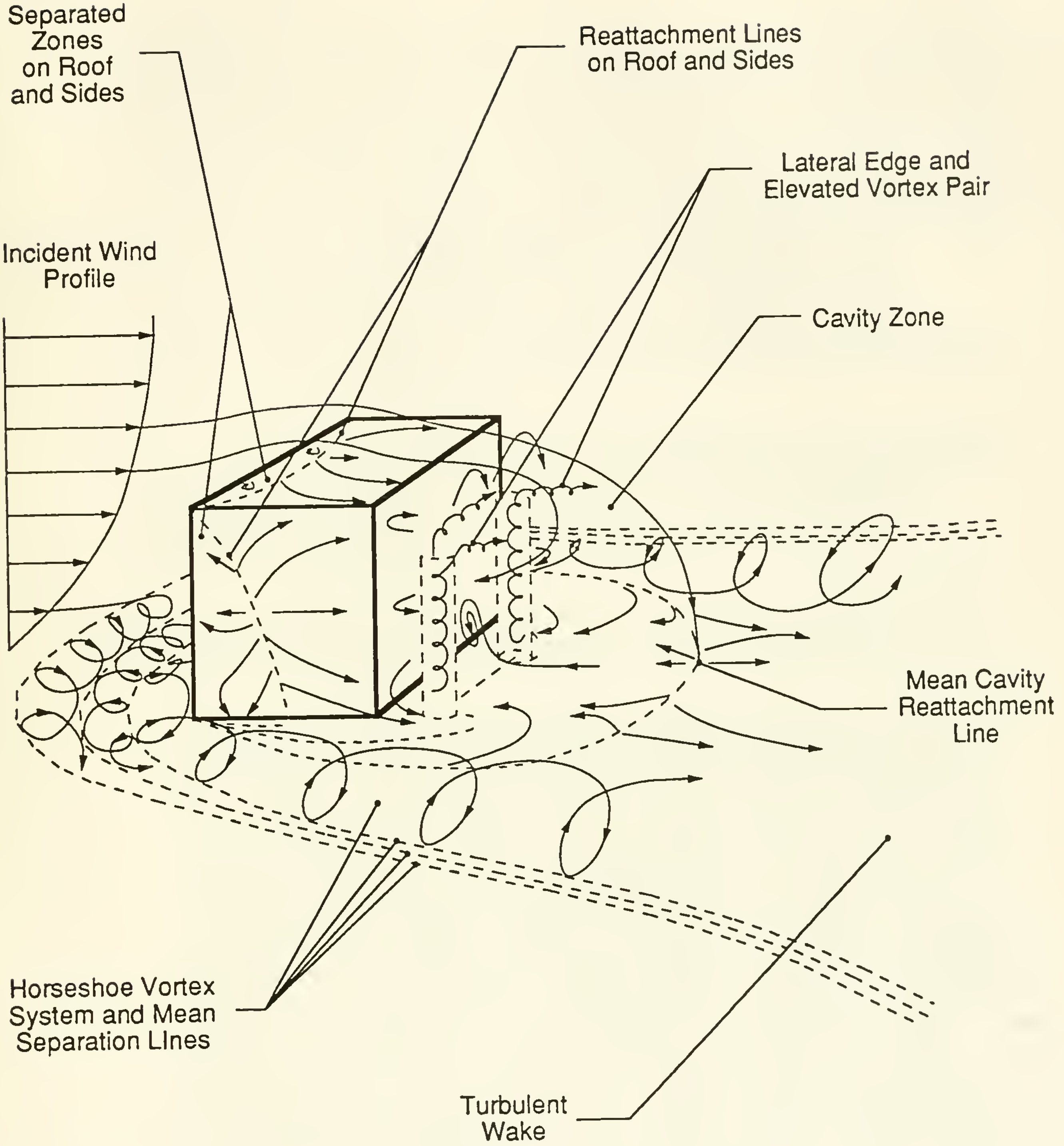

Separated Zones on Roof and Sides
Reattachment Lines on Roof and Sides
Lateral Edge and Elevated Vortex Pair
Incident Wind Profile
Cavity Zone
Mean Cavity Reattachment Line
Horseshoe Vortex System and Mean Separation Lines
Turbulent Wake

Figure 7. Illustration of flow near an isolated sharp-edged building, perpendicular to an approaching wind profile.

- The separated boundary layers move out into the surrounding airstream. If the building is sufficiently long (deep), the undisturbed flow may reattach to the building surface at some downstream location, and eventually will separate again at the downstream edge of the roof and sides. If the roof is not long (deep) enough, reattachment does not occur. In either case, the separated layers curve inward feeding into a "cavity" or recirculation "bubble" immediately downwind of the building. The cavity zone is characterized by low mean speed, high turbulence intensity, recirculation with relatively large residence times of fluid particles "trapped" within the bubble, and low, rather uniform pressure. The exact flow characteristics within this zone depend on the details of the building and are difficult to predict in any general way.

- The frontal eddy (vortex) also interacts with the incident flow near the side of the building, "wrapping around" the building and trailing off downwind on either side near ground level. Viewed from above, this vortex rather resembles a horseshoe. High wind speeds exist in this vortex near the building.

In an actual urban environment, the natural wind field in the boundary layer is further modified in the following ways as it interacts with groups of buildings:

a. Vertical deflection of upper level winds toward the ground on the windward side of tall buildings. When buildings of different heights appear in combinations, the effects described above for an isolated building often combine to cause higher ground level windspeeds than would exist around the structure if they were isolated from each other. As previously described, the pressure gradient on the windward faces deflect the winds normally associated with higher elevations, down to pedestrian level. The low pressure region from the downstream face (cavity zone) of the upstream building enhances the strength of the "frontal vortex" described above thus enhancing the strength of the "horseshoe vortex." Therefore, in such cases, the highest ground level winds are often found around building corners. This corner flow is usually a steady, high-speed wind that gradually drops off to a lower speed farther downwind from the building, but becomes gusty in the process. The flow patterns which typically occur in such situations are illustrated in Figure 8.

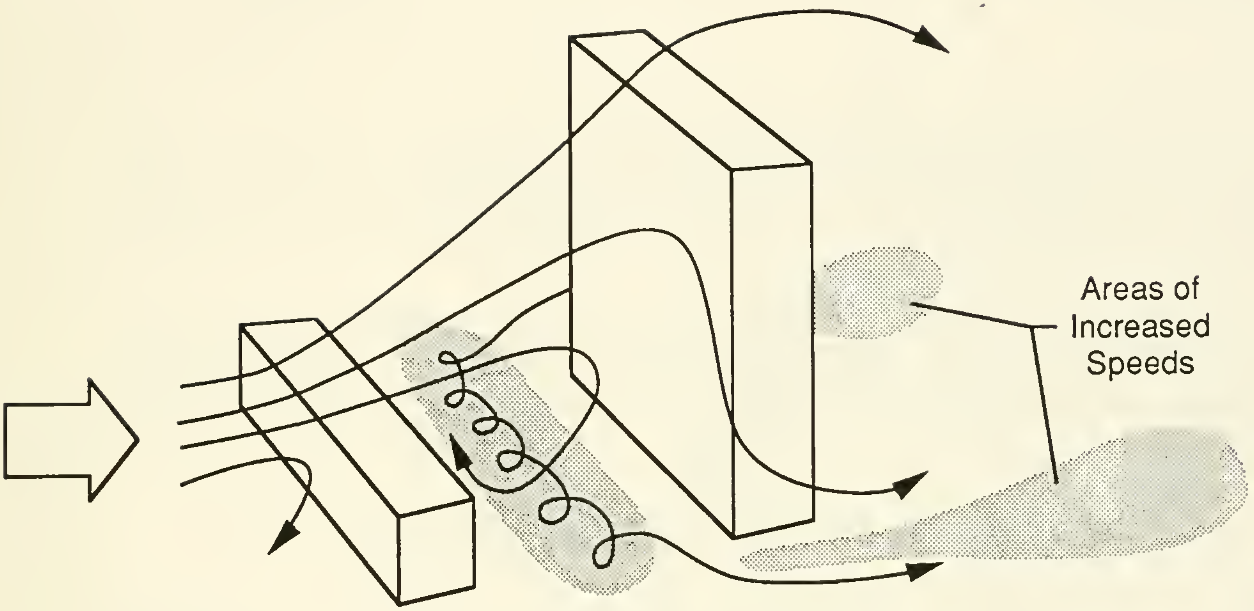


Figure 8. Typical flow patterns between high- and low-rise buildings.

b. Channeling of the air stream between buildings: The "blockage" of approaching flow caused by adjacent buildings facades may cause winds to accelerate as the area available for the approaching wind flow is reduced between the buildings. Channeling increases wind speeds within the channel formed. It also creates likely "hot spots" for increased wind gusts at the corners of the channels.

2.2 Boston Wind Climate

The significance of the siting with respect to frequently occurring wind events is illustrated in Figures 9a-e, in which the annual and seasonal wind statistics for a reference elevation of 960 feet over Boston are shown on a location plan of the proposed development.

The data in Figures 9a-e include probability-of-direction wind statistics (dotted line) (PAZ) and probability-of-velocity exceedance curves (solid lines) P(U) for the reference level winds. A representation of the scales is presented in Table 1:

TABLE 2

Interpretation of Wind "Rose" Scales

Scale Applicable to:	PAZ (Probability that winds will originate from azimuth shown: equivalent 3° segment	P(U) Probability that winds will exceed velocity when winds blow from a direction
1) inner ring	0.01 (1%)	10 m/s (22.5 mph)
2) middle ring	0.02 (2%)	20 m/s (45 mph)
3) outer ring	0.03 (3%)	30 m/s (67.5 mph)

On these plots, the dashed line represents the probability that the wind will originate from a particular azimuth, and the solid contours are lines of equal probability-of-exceedance of various wind speeds to be expected when the winds blow from a given direction. On each "wind rose," the four solid contours start with the inner contour of P=0.1 (10% probability of exceedance) and progress outward to a contour of probability P=0.0001 (.01% probability of exceedance). For example, referring to the wind rose in Figure 9a (Annual Winds), there is an annualized probability of P=0.017 (1.7%) that the winds will

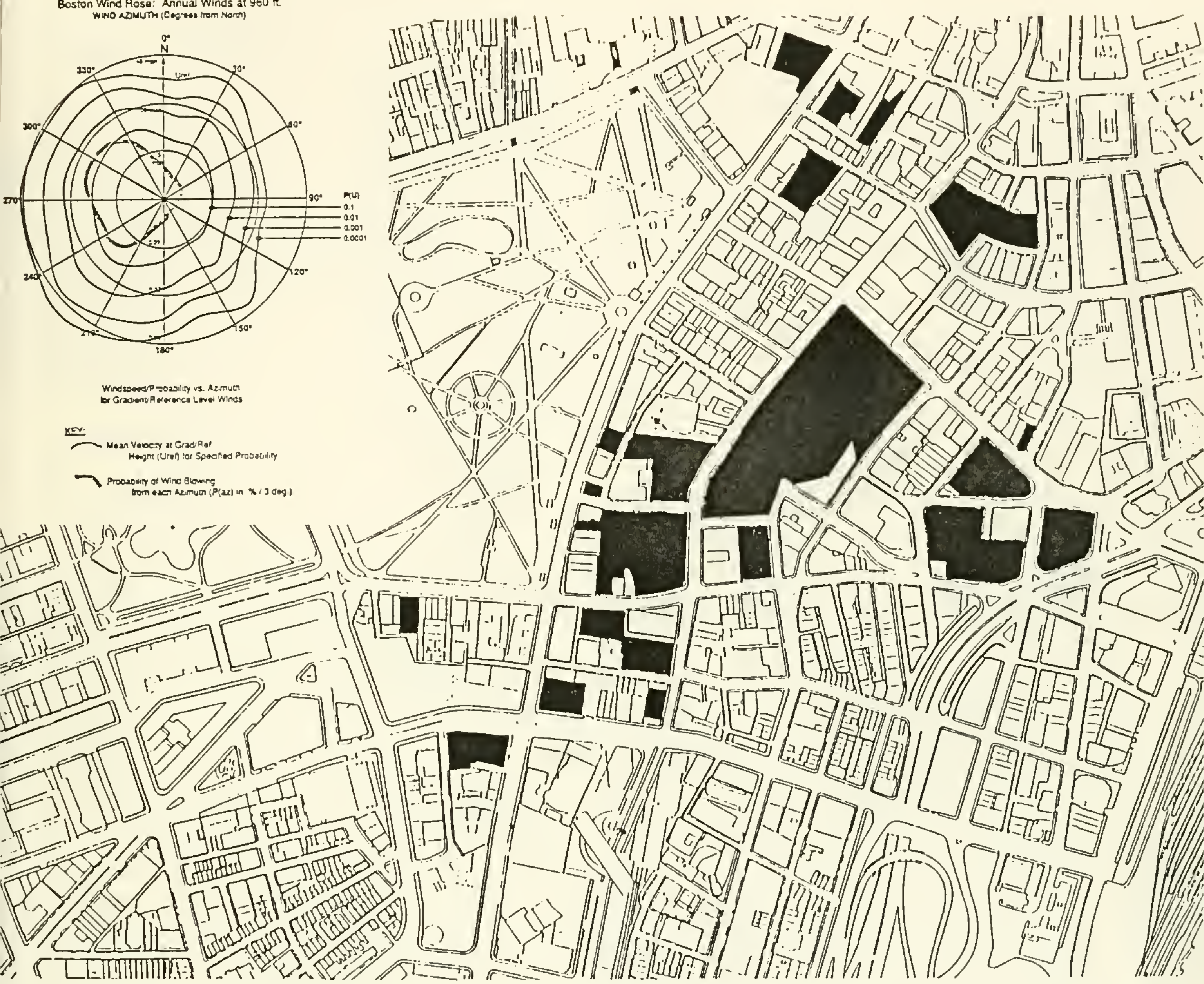

Boston Wind Rose: Annual Winds at 960 ft.
WIND AZIMUTH (Degrees from North)
0°
N
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
Uref
P(U)
0.1
0.01
0.001
0.0001
Windspeed/Probability vs. Azimuth
for Gradient/Reference Level Winds
KEY:
Mean Velocity at Grad/Ref Height (Uref) for Specified Probability
Probability of Wind Blowing from each Azimuth (P(az) in % / 3 deg.)

Figure 9a. Distribution of annual winds over project site.

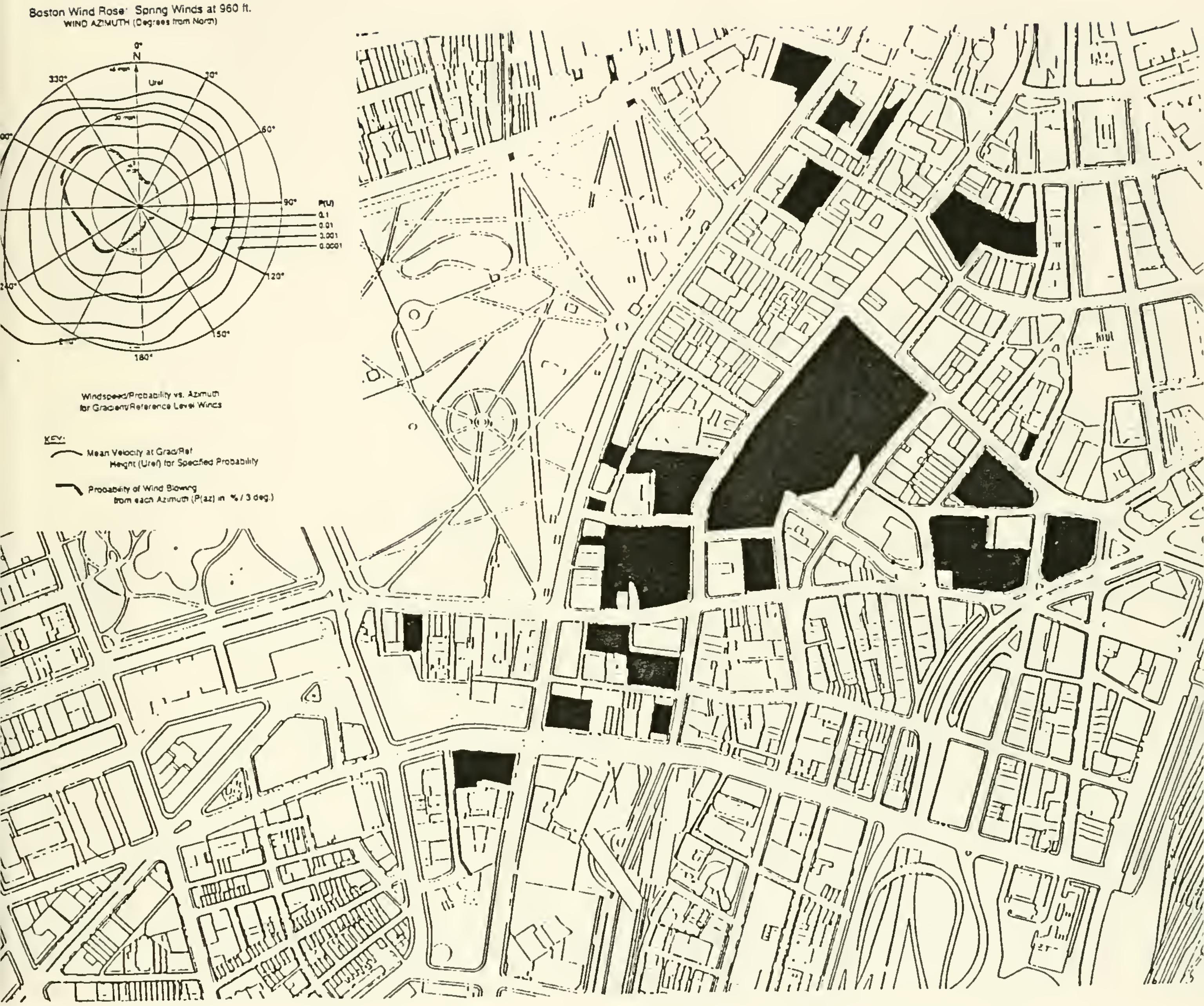

Boston Wind Rose: Spring Winds at 960 ft.
WIND AZIMUTH (Degrees from North)
0°
N
330°
30°
Uref
20 mph
60°
300°
90°
P(U)
0.1
0.01
0.001
0.0001
120°
240°
150°
210°
180°
Windspeed/Probability vs. Azimuth for Gradient/Reference Level Winds
KEY:
Mean Velocity at Grad/Ref Height (Uref) for Specified Probability
Probability of Wind Blowing from each Azimuth (P(az) in % / 3 deg.)

Figure 9b. Spring seasonal wind conditions over project site.

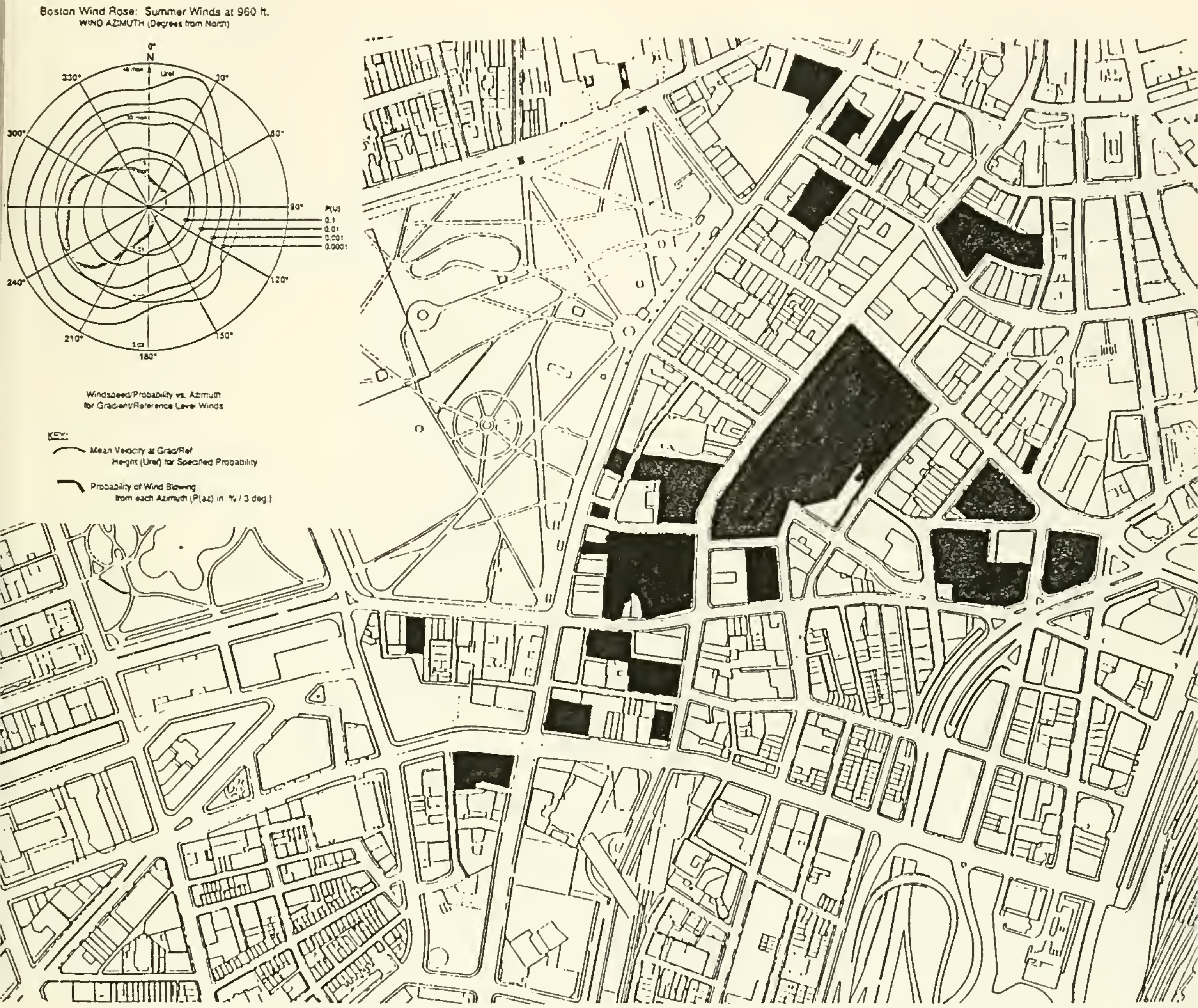

Boston Wind Rose: Summer Winds at 960 ft.
WIND AZIMUTH (Degrees from North)
0°
N
30°
60°
90°
120°
150°
180°
210°
240°
300°
330°
Uref
P(U)
0.1
0.01
0.001
0.0001
Windspeed/Probability vs. Azimuth for Gradient/Reference Level Winds
KEY:
Mean Velocity at Grad/Ref Height (Uref) for Specified Probability
Probability of Wind Blowing from each Azimuth (P(az) in % / 3 deg.)

Figure 9c. Summer seasonal winds over project site.

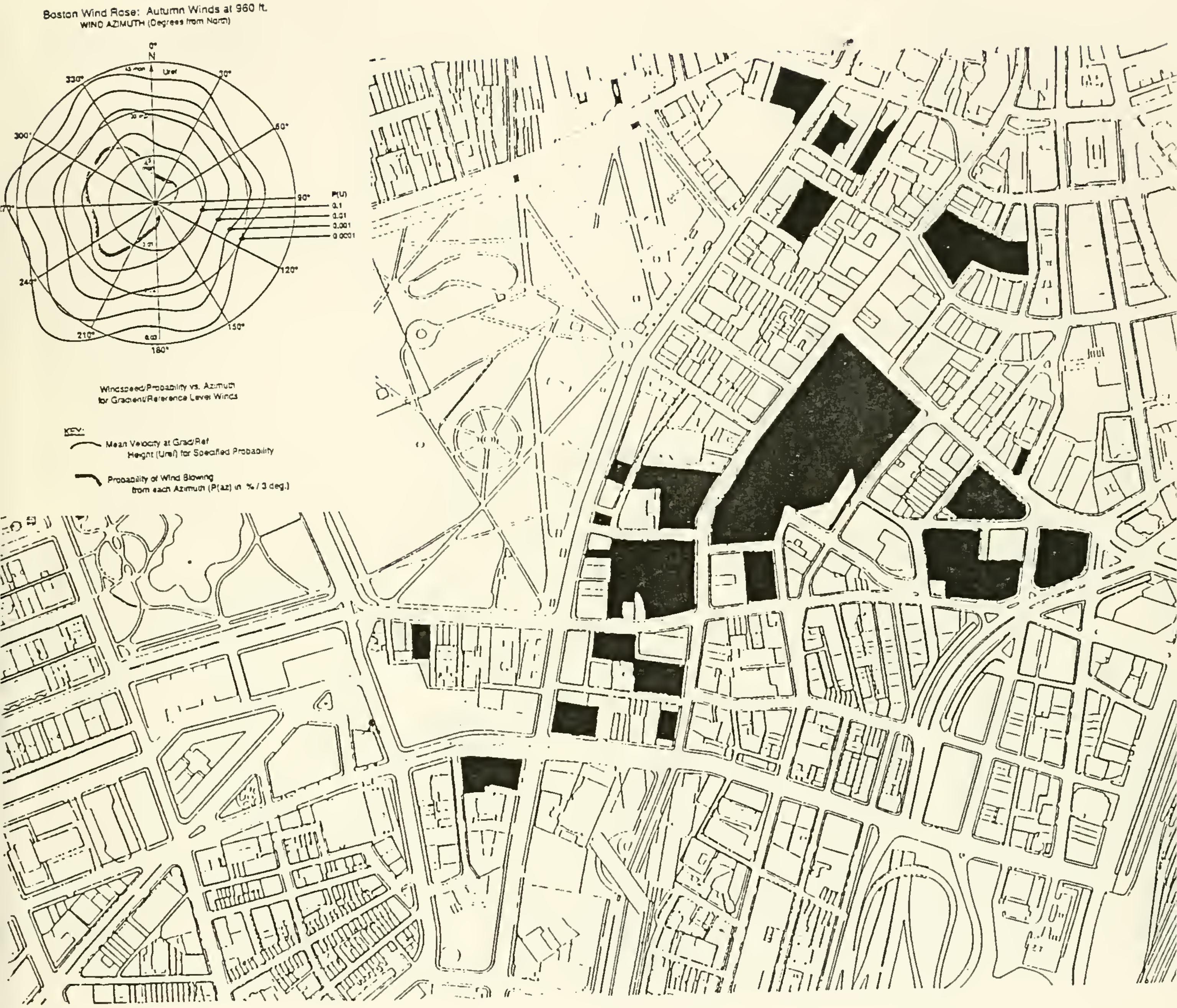

Boston Wind Rose: Autumn Winds at 960 ft.
WIND AZIMUTH (Degrees from North)
0°
N
Uref
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
P(U)
0.1
0.01
0.001
0.0001
Windspeed/Probability vs. Azimuth for Gradient/Reference Level Winds
KEY:
Mean Velocity at Grad/Ref Height (Uref) for Specified Probability
Probability of Wind Blowing from each Azimuth (P(az) in % / 3 deg.)

Figure 9d. Autumn seasonal winds over project site.

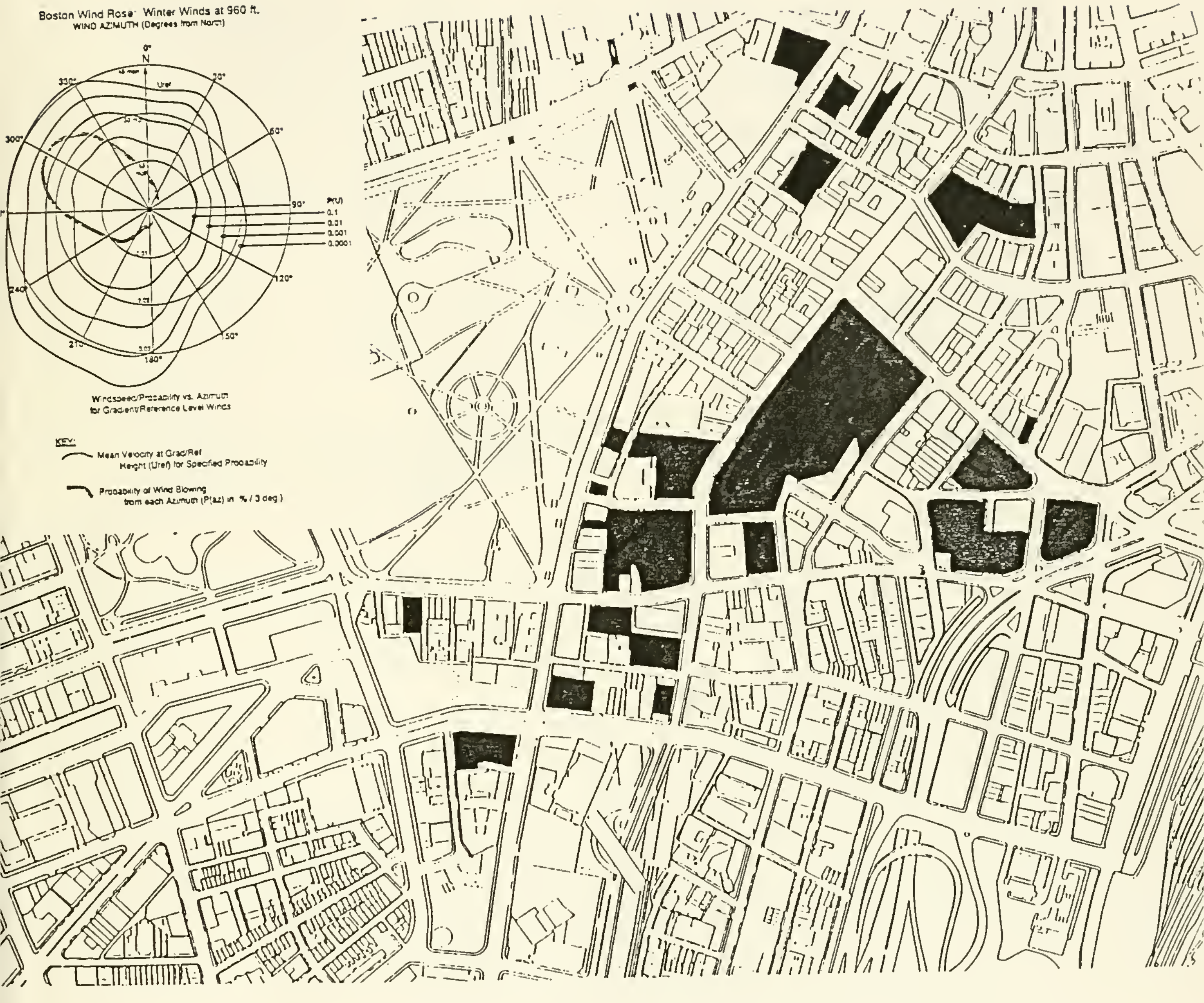

Boston Wind Rose: Winter Winds at 960 ft.
WIND AZIMUTH (Degrees from North)
0°
N
Uref
330°
30°
300°
60°
90°
P(U)
0.1
0.01
0.001
0.0001
120°
240°
150°
210
180°
Windspeed/Probability vs. Azimuth for Gradient/Reference Level Winds
KEY:
Mean Velocity at Grad/Ref Height (Uref) for Specified Probability
Probability of Wind Blowing from each Azimuth (P(az) in % / 3 deg.)

Figure 9e. Winter seasonal winds over project site.

blow from a 3° azimuthal segment centered on 270° there is a 10% probability (P=0.1) that the mean wind speed at the 960 feet reference height will exceed 23.0 m/s, a .1% probability (P=0.001) that the mean wind speed will exceed 28 m/s, and a .01% probability (P=0.0001) that the reference level mean wind speed will exceed 32.0 m/s. When used in conjunction with wind tunnel measurements of pedestrian level wind velocities (which are usually normalized to form a ratio of ground level wind velocity-to-reference level mean wind velocity), an annualized (or seasonal) measurement of velocities which will be exceeded a given percentage of time can be derived.

The data in Figures 9a-e show that the critical wind directions for Boston are generally northwest, west, and southwest, with important, but less significant winds coming from the south, northeast and north.

Winds from other directions must be considered, inasmuch as occasional severe impacts may occur, but in terms of optimizing a massing scheme for the project, the directions identified above are predominant.

3.0 WIND SIGNIFICANCE CRITERIA

Many different wind engineers have attempted to develop criteria for measuring the significance of various wind speeds. The first credible attempt at developing wind criteria is probably the Beaufort Scale developed by Admiral Beaufort based upon his 19th century observations. Contemporary wind significance criteria have been suggested by Davenport (1972), Lawson (1973), Penwarden & Wise (1975), Hunt, Poulton & Mumford (1976), Cohen et al. (1977), and Melbourne (1978).

The various criteria can often be quite confusing. Some are based upon average wind speeds, others upon wind gust speeds. Some are based upon type of activity to be accommodated. Many are based on combinations of these factors. Because these criteria measure human response to an environmental phenomenon, all are influenced, to some extent, by the judgment of the authors and the windiness of the environment to which the authors and their test populations are normally exposed. In short, acceptability of winds, like temperature, may vary considerably from region-to-region and from person to person.

In Boston, the primary criterion used is the BRA wind design guidance level, which was derived from several studies, but relied most heavily on evaluations of the Cohen studies, which were conducted in Boston. In these studies, measured wind speeds were correlated with the observed response of the pedestrian population in the downtown area. BRA has suggested that effective gust velocities (defined as average hourly wind speeds + 1.5 times the root-mean-square of the wind fluctuations) exceeded 1% of the time should be less than 31 mph. This criterion was selected as the primary criterion since it reflects local perceptions of acceptable wind levels, and because it is a relatively straightforward, easily interpreted design guideline. Table 3 summarizes pedestrian wind criteria based upon the effective gust velocity. This criterion has also been applied by BRA in all wind studies for tall buildings in Boston over the past several years. This criterion has typically been applied for design guidance rather than as an absolute acceptability measure. BRA has asked prospective developers to explore mitigating measures for designs which are predicted to exceed this design guidance criterion.

TABLE 3: Recommended Pedestrian Safety/Comfort Standards for Urban Winds

Activity Area	Effective Gust Velocity (egv)	Permitted Occurrence Frequency
Limit for safety- All pedestrian areas	30.4 mph	1.0%**
Major walkways- Especially principal egress path for high-rise buildings	30.4 mph	1.0%**
Other Pedestrian Walkways- Including street and arcade shopping areas	25 mph	5%
Open plaza and park sitting areas, open-air restaurants	9 mph	20%

---

*The effective gust velocity (egv) is defined as egv = U + 1.5 urms, where U is the mean windspeed at a particular location and urms is the root mean square of the fluctuating velocity component measured at the same locations over the same time interval.

**The effective gust velocity with a 1% occurrence frequency was derived by interpolation of data from Cohen et al., 1977; the actual value proposed for a 0.1% occurrence frequency is 35.6 mph.

An alternate supplemental set of criteria which have been used occasionally are the Melbourne "International Pedestrian Comfort Criteria" depicted in Figure 10. These are probabilistic criteria for hourly average pedestrian winds for a variety of human activities. The vertical scale is the average hourly velocity in miles per hour; the horizontal scale is the frequency of occurrence of the wind speed. The four curves on the graph define five separate comfort zones. The upper zone represents hazardous wind speeds, the second zone indicates wind speeds that may be safe but uncomfortable for walking, the third zone indicates a comfortable walking environment, the fourth zone indicates wind speeds low enough to accommodate short-term stationary exposures, and the fifth and final zone indicates wind speeds acceptable to accommodate long-term stationary activities.

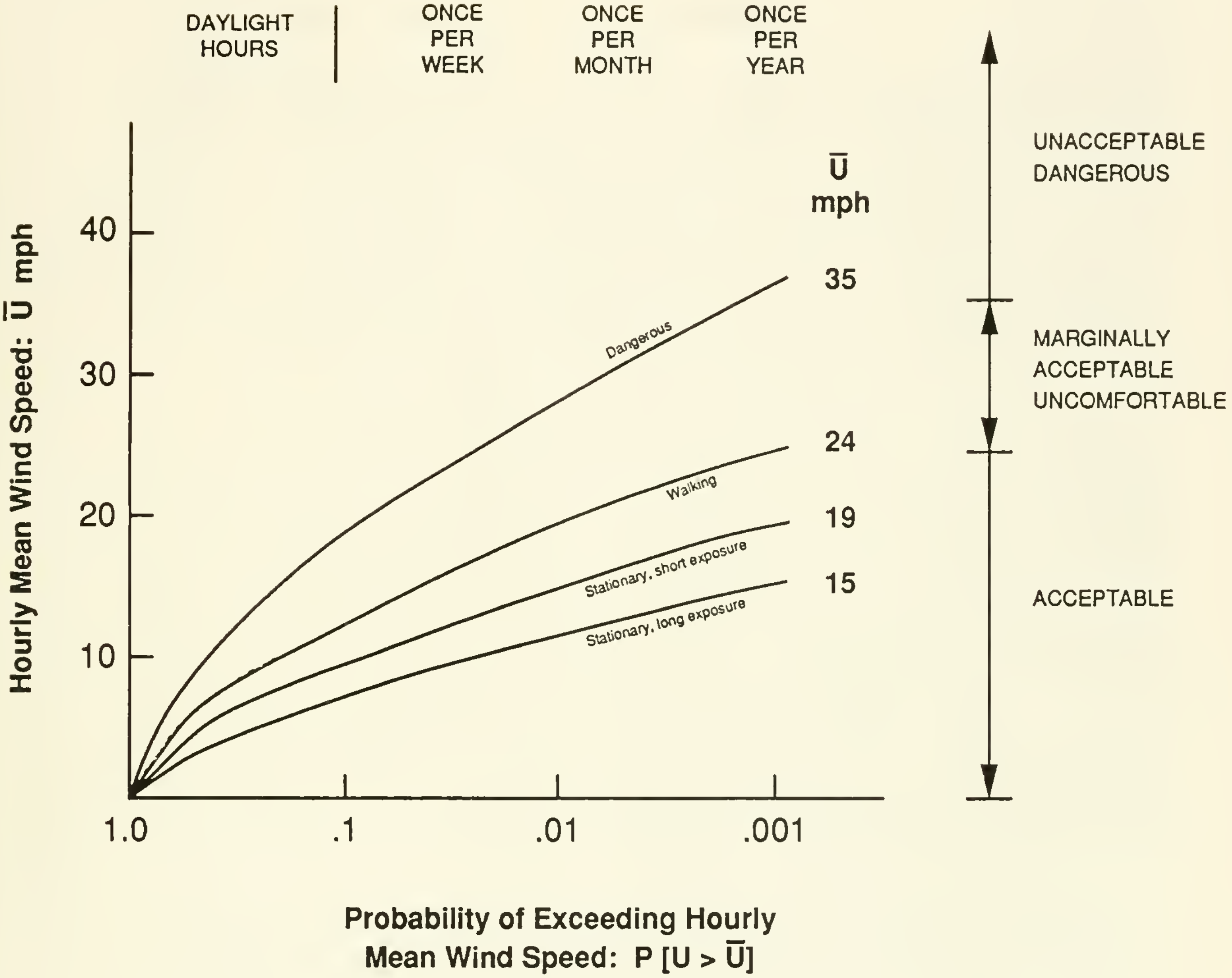


Figure 10. Melbourne's criteria for average hourly pedestrian winds.

4.0 QUALITATIVE ANALYSIS OF PROPOSED PROJECT

Our qualitative assessment of wind conditions entailed the use of smoke visualization as well as erosion particle studies for key wind directions (Northwest, Southwest, and Southeast). Placing one or multiple smoke sources in the area outlined in Figure 2 clarified the flow dynamics in and above the pedestrian environment, allowing the major flow phenomena to be defined. The results were videotaped from overhead and the side simultaneously in order to capture the three dimensional flow characteristics. By itself, smoke visualization leads to a basic understanding of the mechanics of the wind/building interactions, but it does not quantify the problem areas.

A semi-quantitative technique which can identify pedestrian areas which will be impacted is particle erosion. Using this technique, we rely on the forces of the wind on small particles to remove their preferentiality from areas of highest windspeed and either depositing them or leaving them undisturbed in areas where lower windspeeds occur. By evenly spreading low density erosion particles lightly along the pedestrian level and tracing their movement, distinct areas of accelerated winds are outlined by the absence of particles. For example, Figure 11 shows a typical "erosion" particle distribution. As the wind approaches from right to left (northwest winds), the interaction of the winds with the buildings results in the particle distribution illustrated in Figure 12. Comparing the particle distribution for the full-build condition (Figure 13) with the existing condition (Figure 12) demonstrates how little the Boston Common is affected by the additional buildings.

The combination of smoke visualization and erosion particles provides an accurate and insightful approach to developing clear understanding of the flow patterns at particular wind directions. Figures 14 and 15 demonstrate how these technologies are used in tandem to produce a clear understanding of pedestrian winds with a northwesterly wind and the differences between the existing and proposed conditions. These techniques are limited by the number of wind directions that can be tested and the inability to produce accurate velocity measurements; therefore, hot wire anemometers were used as a means of quantitative assessment (see Section 5).

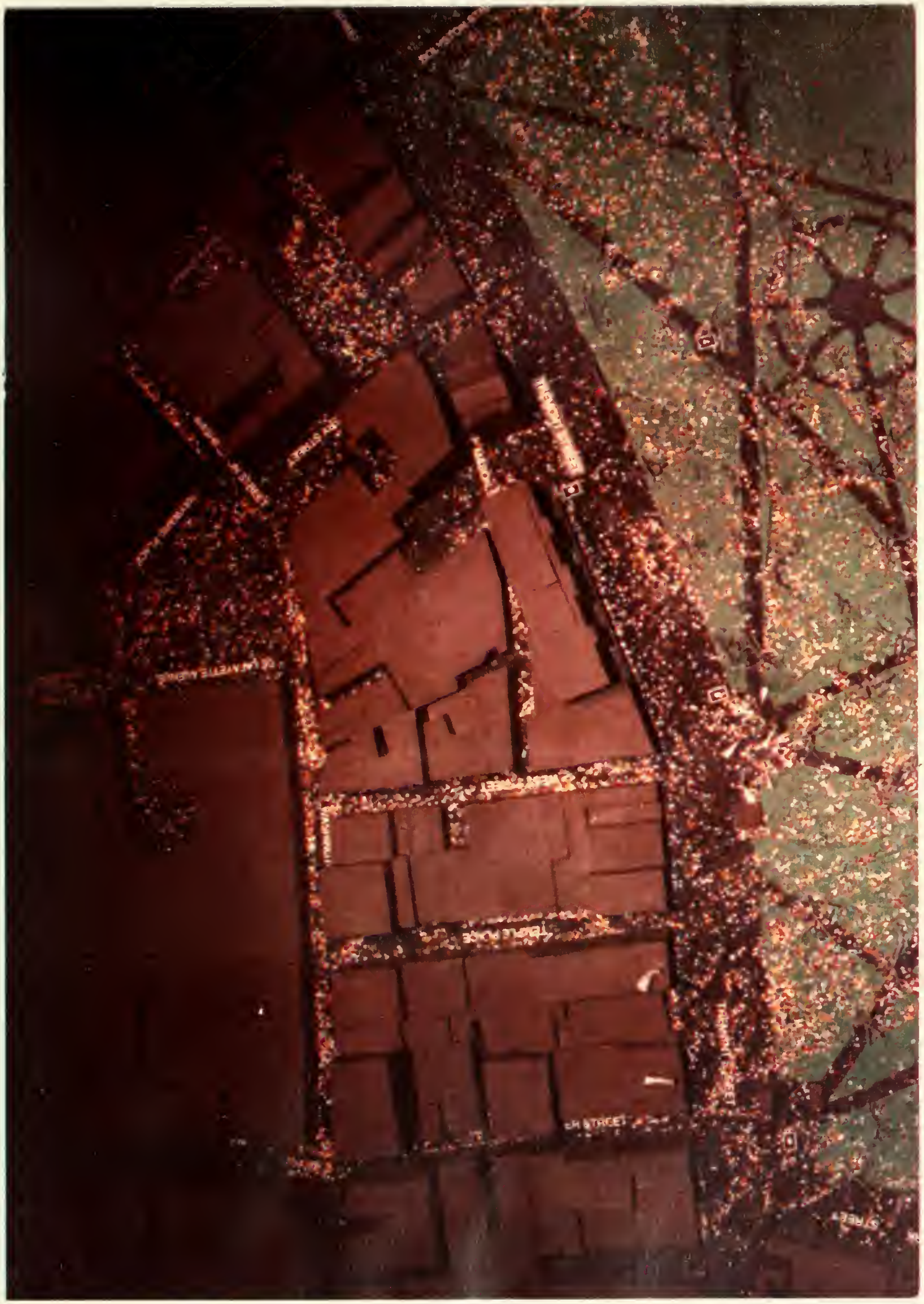


Figure 11. Typical initial dispersion of erosion particles.

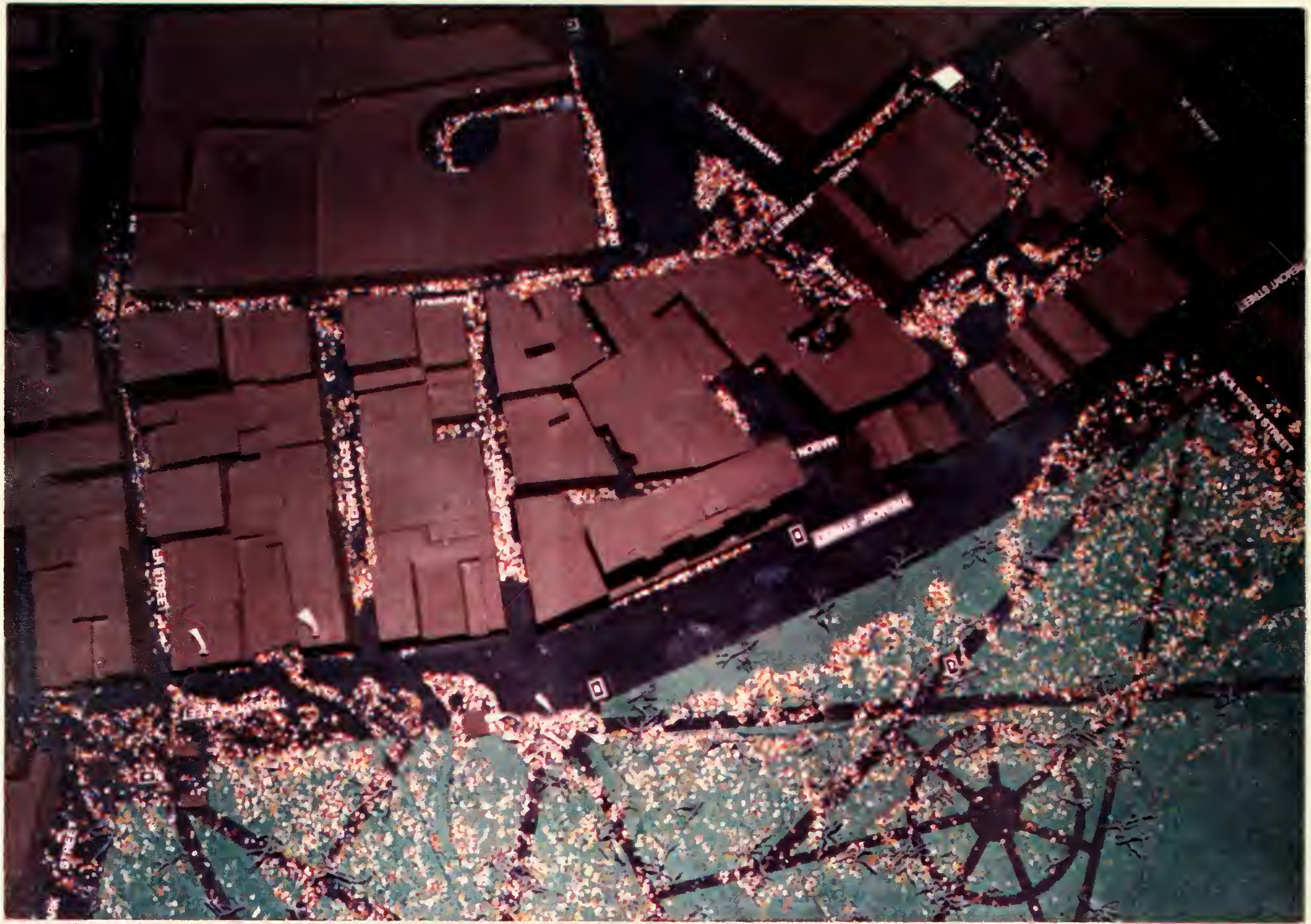


Figure 12. Erosion dispersion for northwest winds after a 5-minute lapse, existing condition.

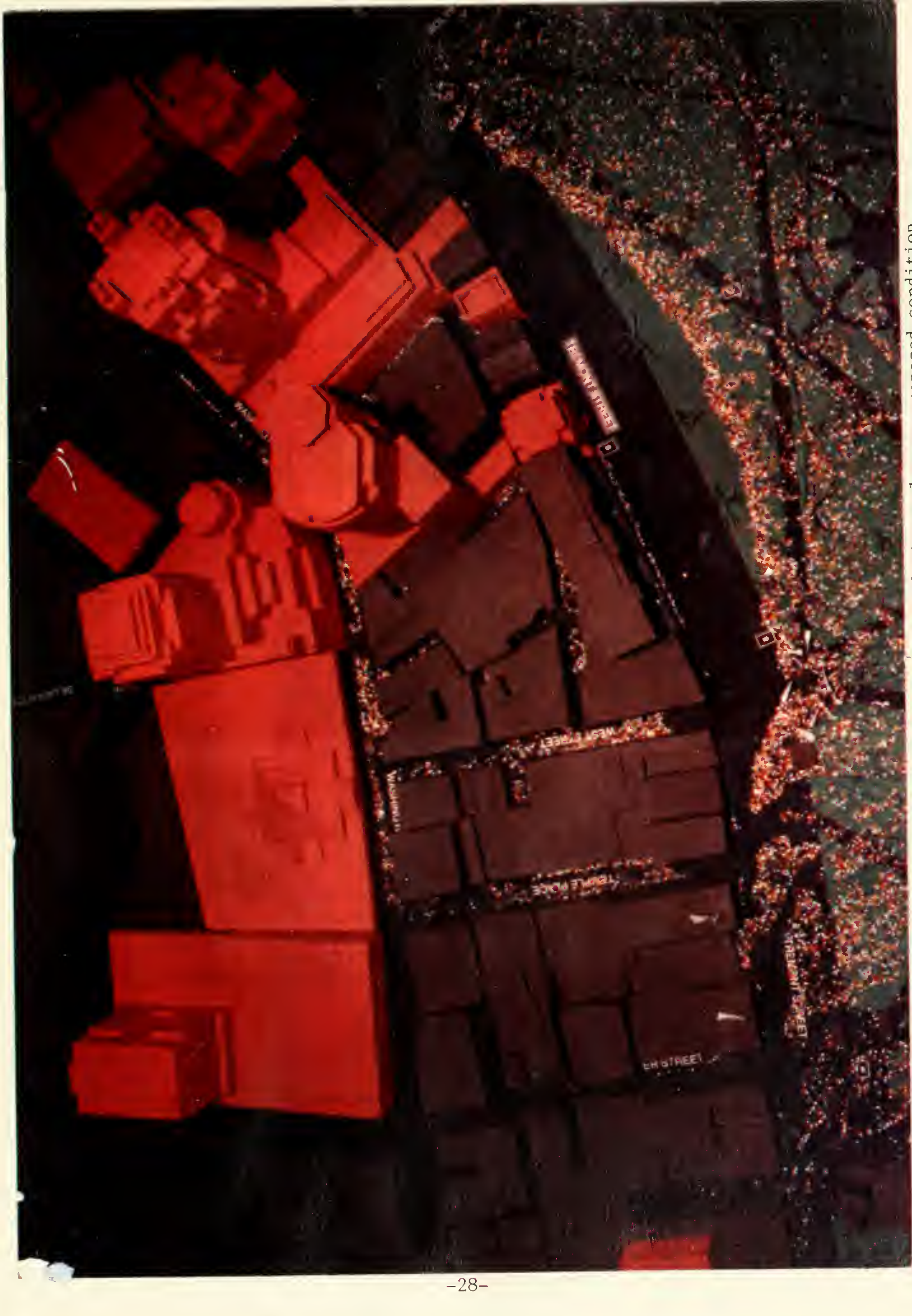


Figure 13. Erosion dispersion for northwest winds after a 5-minute lapse, proposed condition.

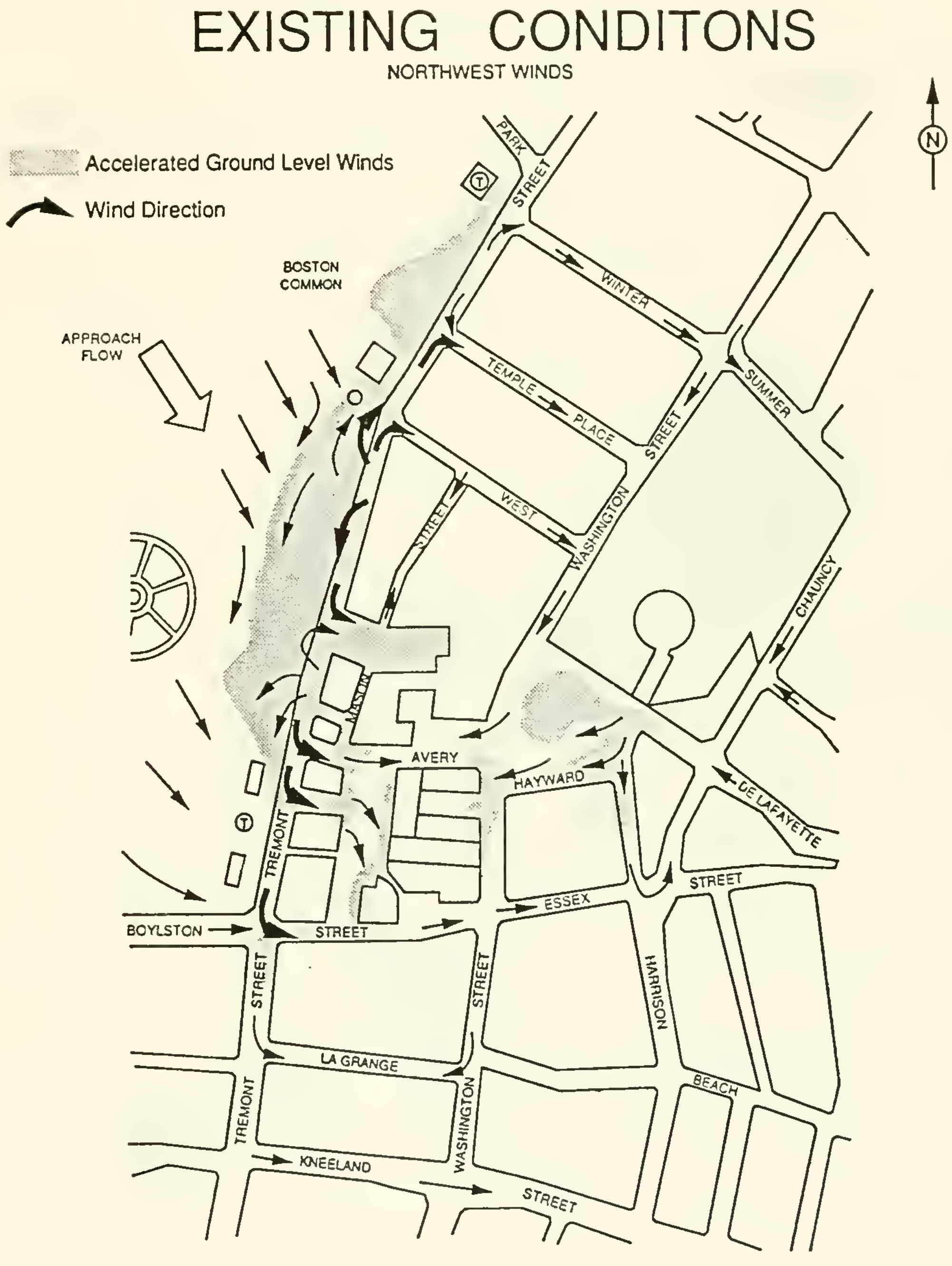
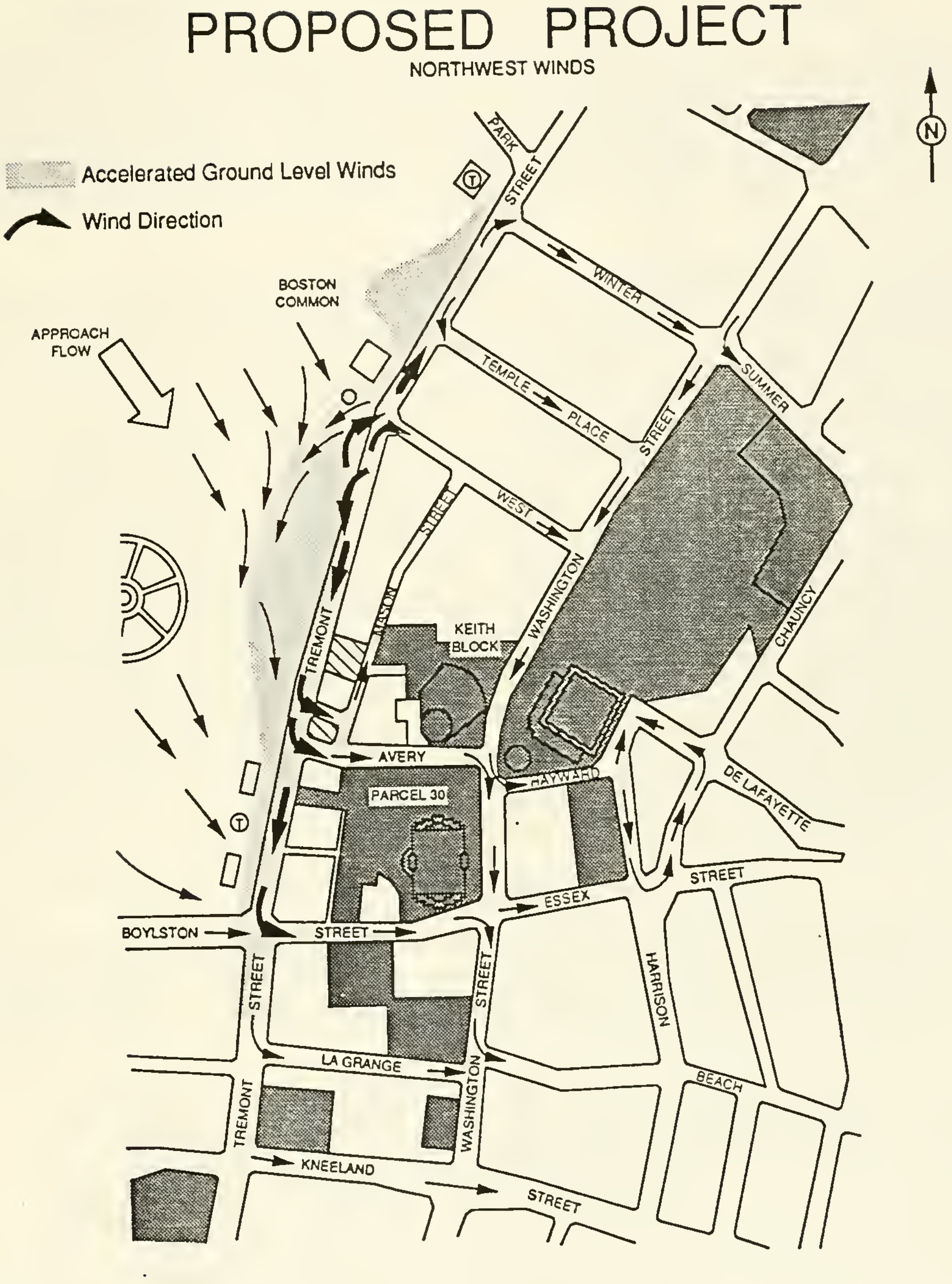


Figure 14. Qualitative results for the existing condition in a northwest wind.



PROPOSED PROJECT
NORTHWEST WINDS

Figure 15. Qualitative results for the proposed condition in a northwest wind.

5.0 QUANTITATIVE ANALYSIS

5.1 Technique

Quantitative assessment of wind conditions is carried out through the combination of (1) velocity-versus-azimuth measurements taken in a wind tunnel which properly simulates the lower atmosphere, and (2) the long-term statistics of the "undisturbed" wind at the local gradient height (such as was shown in Figure 9a).

The velocity-versus-azimuth data is measured in a boundary layer wind tunnel (Figure 16), by placing velocity-sensitive devices (hot wire anemometers) on a scale model which is mounted on a turntable. The anemometers are placed in selected locations a distance equal to six feet above the local ground surface. Then the "pedestrian level" speeds (Vp) are measured as a fraction of the gradient velocity (Vg) every 3° of wind direction. The result is a file of Vp/Vg which assumes a constant velocity at gradient height for all directions (see Figure 17 for sample). However, since we know the direction and speed of Vg varies with season, time of day, and with large-scale meteorological events, we can produce estimates of the probability that certain velocity thresholds will be exceeded by merging the meteorological wind statistics for Vg with the wind tunnel-derived site-specific Vp/Vg data. A typical result is shown in top of Figure 18. This procedure can be further manipulated to produce estimates of probability-of-exceedence of certain velocity threshold on a seasonal basis; the bottom of Figure 18 provides a sample of such calculations.

5.2 Locations and Site Configurations Tested

Figures 19 provides a map of the locations for which velocity data (listed in Table 4) were measured with hot-wire anemometers. Test points were selected based upon one or more criteria:

(1) major pedestrian way and building entrances
(2) sensitive population using the local area
(3) experience of high wind conditions already existing
(4) results of qualitative analysis
(5) BRA request

The site configurations tested included:

(1) Existing conditions as of 1/89.
(2) "Full build of Midtown District to include buildings on Table 1, as located in Figure 4.

TABLE 4

Gust Velocities (mph)			
Point	Existing Conditions (1% Probability) All Wind Directions	Full Build (1% Probability) All Wind Directions	Peak Site Measurement (10 min. sample) NW (330°) wind only
1	15	19	6
2	17	19	-
3	24	7.5	3
4	11.5	24	15
5	28	31	33
6	32	23	32
7	17	17	15
8	32	35	18
9	13	14	9
10	11	16	2
11	15	16	-
12	24	19	-
Northeast Corner of Prudential Building			32
Northeast Corner of John Hancock Building			29
Boston Shore of Charles River			29
Entrance to McCormack Building			37
12 Foot Height at Logan Airport			30

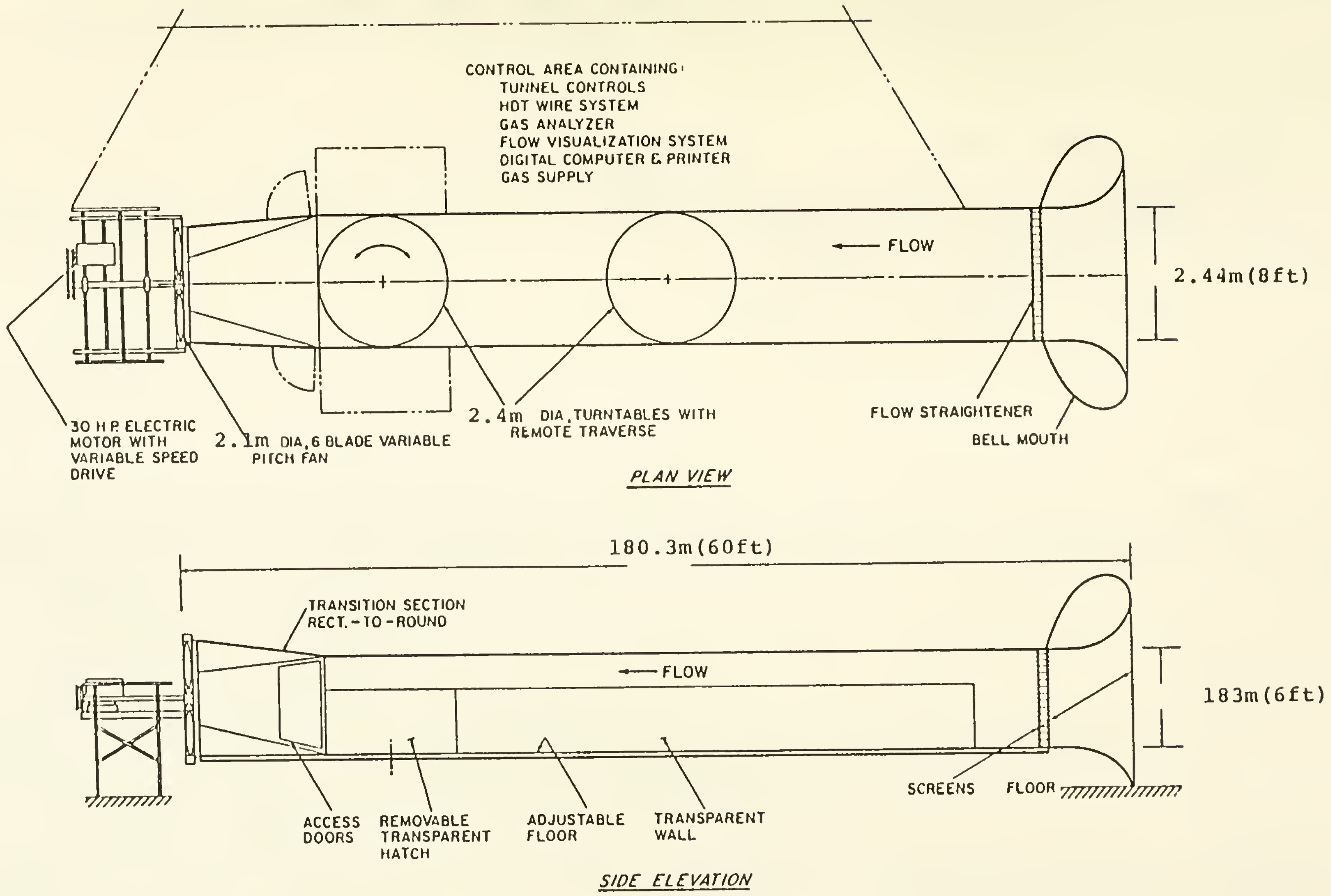

CONTROL AREA CONTAINING:
TUNNEL CONTROLS
HOT WIRE SYSTEM
GAS ANALYZER
FLOW VISUALIZATION SYSTEM
DIGITAL COMPUTER & PRINTER
GAS SUPPLY
← FLOW
2.44m(8ft)
30 H.P. ELECTRIC MOTOR WITH VARIABLE SPEED DRIVE
2.1m DIA, 6 BLADE VARIABLE PITCH FAN
2.4m DIA, TURNTABLES WITH REMOTE TRAVERSE
FLOW STRAIGHTENER
BELL MOUTH
PLAN VIEW
180.3m(60ft)
TRANSITION SECTION RECT.-TO-ROUND
← FLOW
183m(6ft)
ACCESS DOORS
REMOVABLE TRANSPARENT HATCH
ADJUSTABLE FLOOR
TRANSPARENT WALL
SCREENS
FLOOR
SIDE ELEVATION

Figure 16. Boston University Boundary Layer Wind Tunnel.

V_{grad} = 11 m/s - To convert to mph, multiply mps by 2.24.

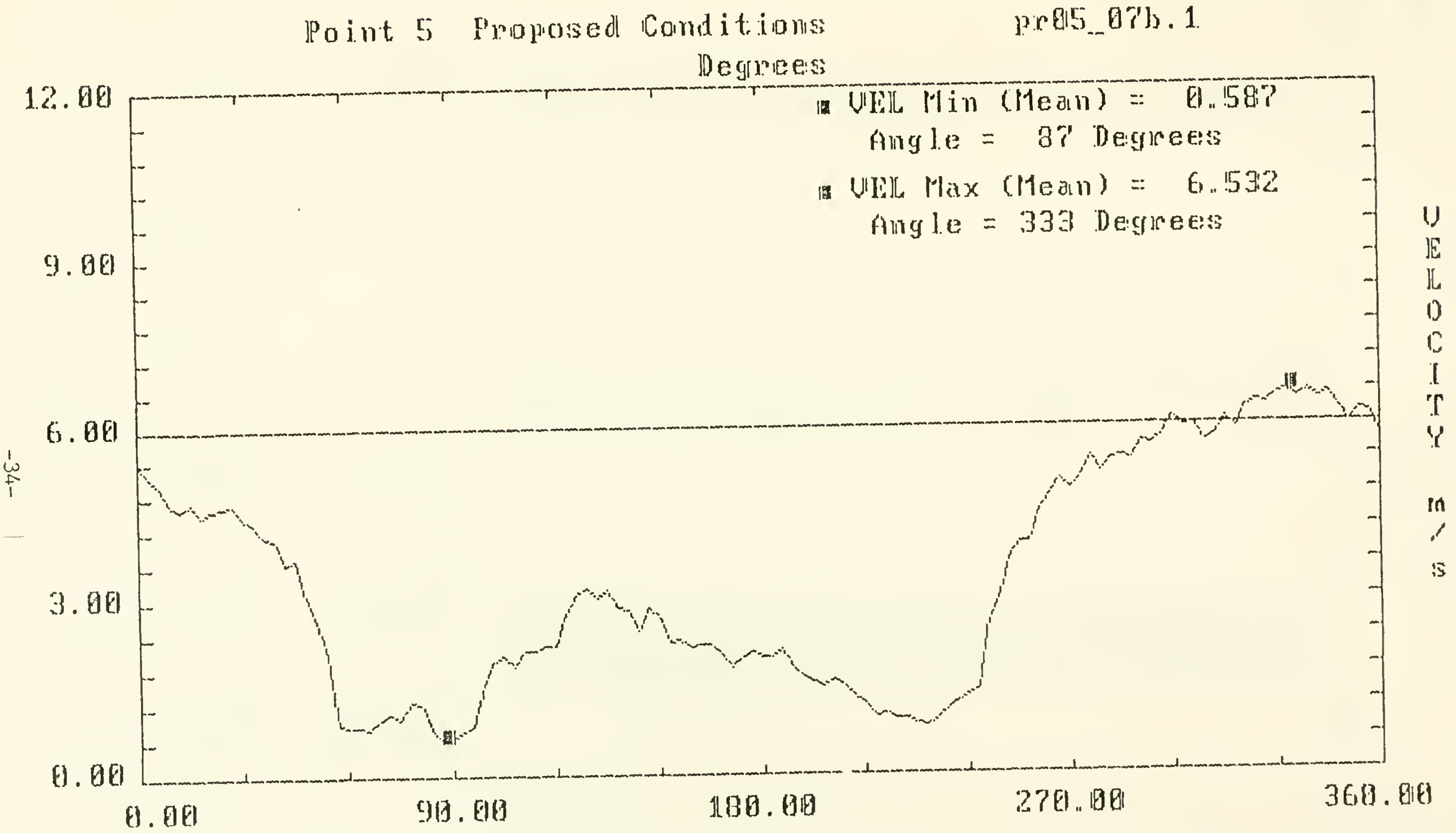


Figure 17. Example of velocity vs. wind azimuth with gradient velocity of 11 m/s.

Sensor Location #5 - To convert to mph, multiply mps by 2.24.

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Velocity (m/s)	Probability Vmean	Probability Vgust
0.00	1.000000	1.000000
0.50	-0.915478	0.971571
1.00	0.779589	0.903791
1.50	0.672558	0.820927
2.00	0.592324	0.738993
2.50	0.526323	0.664183
3.00	0.466795	0.597340
3.50	0.410602	0.537396
4.00	0.357116	0.482905
4.50	0.306709	0.432647
5.00	0.259977	0.385820
5.50	0.217428	0.342001
6.00	0.179386	0.301044
6.50	0.145974	0.262960
7.00	0.117139	0.227827
7.50	0.092680	0.195723
8.00	0.072286	0.166693
8.50	0.055569	0.140726
9.00	0.042097	0.117751
9.50	0.031423	0.097647
10.00	0.023108	0.080247
10.50	0.016740	0.065349
11.00	0.011945	0.052730
11.50	0.008394	0.042158
12.00	0.005809	0.033393
12.50	0.003959	0.026205
13.00	0.002657	0.020372
13.50	0.001756	0.015689
14.00	0.001143	0.011969
14.50	0.000732	0.009045
15.00	0.000462	0.006771
15.50	0.000287	0.005021
16.00	0.000176	0.003689
16.50	0.000106	0.002684
17.00	0.000063	0.001935
17.50	0.000037	0.001383
18.00	0.000021	0.000979
18.50	0.000012	0.000686
19.00	0.000007	0.000477
19.50	0.000004	0.000329
20.00	0.000002	0.000225
20.50	0.000001	0.000152
21.00	0.000001	0.000102
21.50	0.000000	0.000068
22.00	0.000000	0.000045
22.50	0.000000	0.000030
23.00	0.000000	0.000019
23.50	0.000000	0.000013
24.00	0.000000	0.000008
24.50	0.000000	0.000005
25.00	0.000000	0.000003

Vmean (m/s)

Probability	FALL	WINTER	SPRING	SUMMER	ANNUAL
50%	2.536	3.870	2.770	1.912	2.721
20%	5.410	6.849	5.976	4.451	5.729
10%	6.941	8.394	7.731	5.830	7.350
5%	8.214	9.671	9.179	6.959	8.707
1%	10.591	12.037	11.884	9.119	11.274

Vgust (m/s)

Probability	FALL	WINTER	SPRING	SUMMER	ANNUAL
50%	3.670	5.162	3.905	2.896	3.843
20%	7.087	8.805	7.725	5.869	7.433
10%	8.980	10.728	9.900	7.567	9.441
5%	10.554	12.313	11.722	8.972	11.129
1%	13.521	15.277	15.145	11.646	14.337

Figure 18. Example reduction of annual and seasonal statistical data.

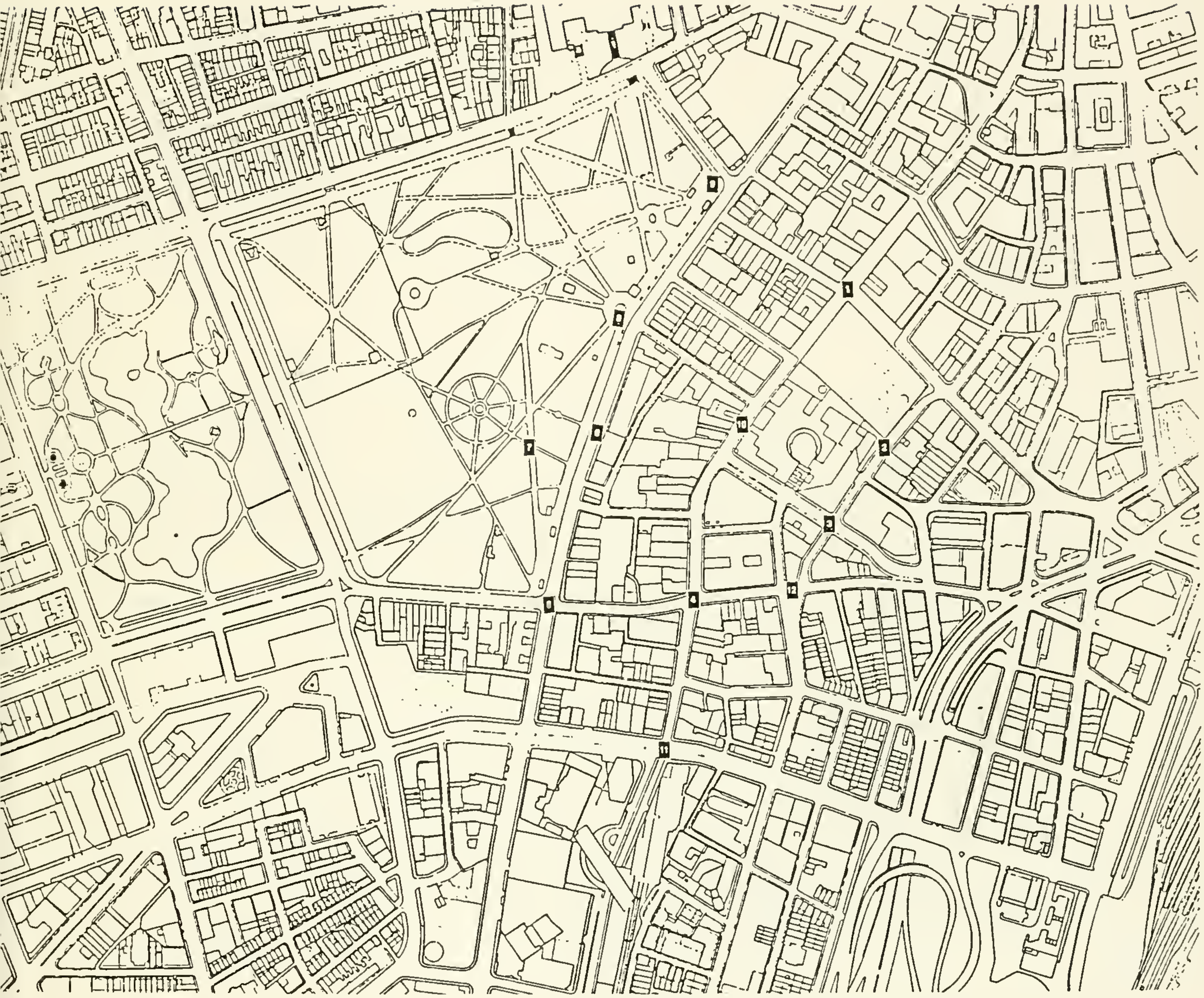

Figure 19. Locations of test points.

The existing surroundings and topography were modeled to a distance of 1500 ft from the center of the site. The wind profile used upwind of the turntable was an exponential profile with an exponent of approximately $\alpha = 0.3$. Note that over the Boston Common, this profile adjusts to a "flatter" profile with higher speed winds penetrating closer to the ground. The Common portion of the model contained trees which were aerodynamically scaled (based upon previous work by the author) to produce the same wind resistance as deciduous trees in the winter, thus producing a worst-case wind exposure of the actual site. Note that the tree heights and locations were carefully compared with the actual locations on the Common.

5.3 Analysis of Results

Two types of quantitative analysis were used: (1) hot-wire anemometer measurements in a wind tunnel and (2) on-site measurements. A summary of results is presented in Table 4. The wind tunnel data represents gust velocities which are not expected to exceed more than 1% of the time, and the on-site measurements represent the peak velocity recorded for a 10-minute sample, measured with a hand-held propeller velocity meter. The on-site measurements were taken on 4 January 1989, with winds from the Northwest and 30 mph gust velocities being recorded by Logan Airport, Boston at a 12-foot height. Our on-site measurements were taken at a height of eight feet.

In general, the buildings produce both favorable and adverse impacts, depending upon the specific area. Tall buildings have a tendency to direct upper level, higher velocity winds downward into the pedestrian environment causing wind speeds to be increased in the immediate vicinity. Washington Street experiences a rise in wind speeds due to the Lafayette II and Commonwealth Center developments, but the wind climate remains within comfortable levels for most pedestrian activities. Downwind of tall buildings, sheltering effects occur resulting in lower wind speeds for most cases, such as Chinatown for northwest winds.

One of the windiest areas is presently, and will remain, along Tremont Street. Strong winds there are generated by the unimpeded wind blowing across the Common, interacting with the abrupt change in surface topography created by the existing Tremont-on-the-Common (TOC) structure. The adjacent Parkside East and Parkside-at-Mason buildings ameliorate the strong winds at the southern corner of TOC, but result in slightly higher windspeed from Avery to Boylston Street. Special attention should be focussed on the corner of Tremont and Boylston, where the gust velocity exceeds the BRA guideline of 31 mph, for the proposed conditions only. Future building

designs should take into consideration the severe wind conditions along Tremont Street.

The Boston Common's wind climate remains virtually unchanged by the addition of the proposed buildings. The areas directly across from TOC along Tremont Street encounter strong winds which increase slightly for the proposed conditions.

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